JUNO

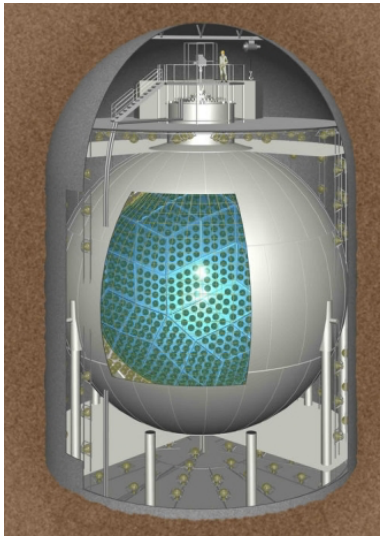
Small PMT system

FCPPL – Marseille - May 2018

C.Cerna

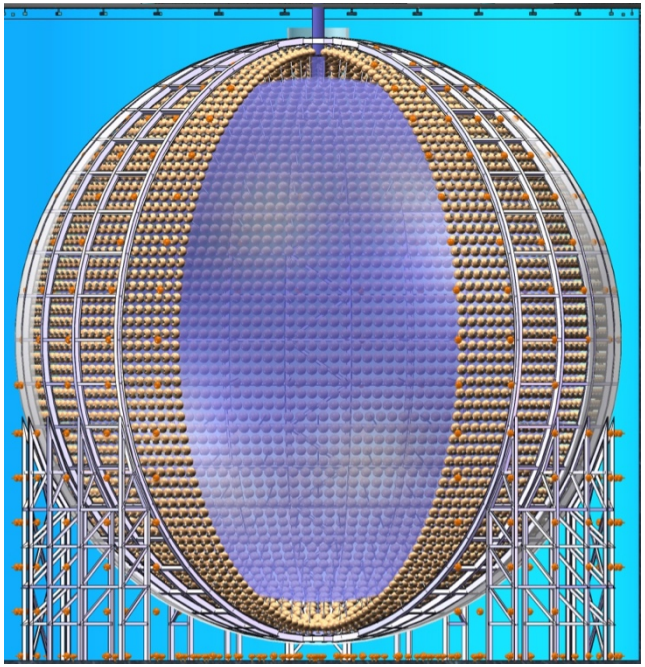
on behalf of the JUNO SPMT dream team

JUNO photomultipliers



Kamland
1,000 t
1,325 x 17’’+ 544 x 20’’
32%
6% /√E

Borexino
300t
2,200 x 8’’
34%
5% /√E



JUNO
20,000 t
- **18,000 x 20’’**

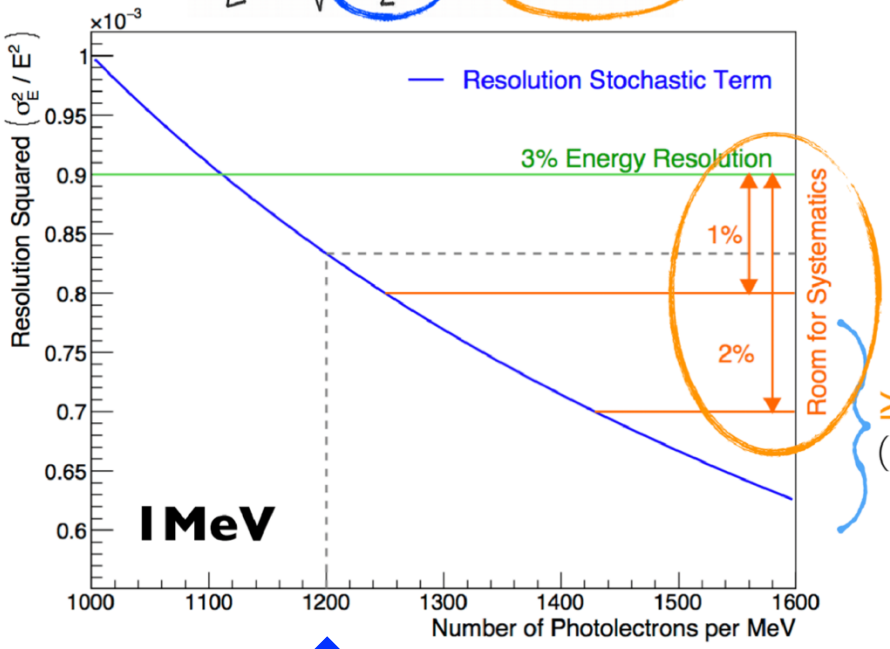
75% coverage
>1200 PE/MeV → 3% /√E

20’’	
NNVT	**Hamamatsu**
5,000 MCP	13,000 Dynode
DE = QE x CE 27%	
Gain 1^E7	
SPE Resol. ~30%	
TTS 5.1ns	**1.2ns**

Challenging calorimetry systematic control

$$\frac{\sigma(E)}{E} = \sqrt{\left(\frac{\sigma^2_{STOCH}}{E}\right) + \sigma^2_{NON-STOCH}(E)}$$

≤3% @ 1MeV



But not sufficient

≥2%
(previous experiments)

Lot of light is needed

- **20'' PMT photon range [10^{-1} - 10]**

Nonlinearity contributes to non-uniformity
→ deterioration of the energy resolution

RISK of non-linearity mixing : LY & quenching, propagation, detection, reconstruction
RISK of converting a vertex difference in a charge mis-reconstruction

CHALLENGE: calibrate the non linear response to sub-percent level

Challenging calorimetry systematic control

$$\frac{\sigma(E)}{E} = \sqrt{\left(\frac{\sigma^2_{STOCH}}{E}\right) + \sigma^2_{NON-STOCH}(E)}$$

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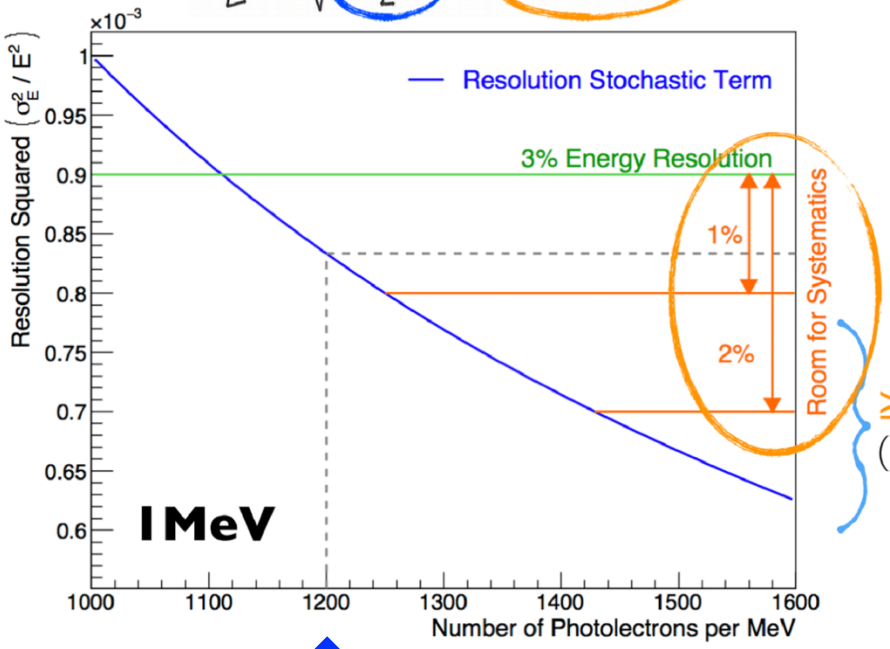

But not sufficient

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Lot of light is needed

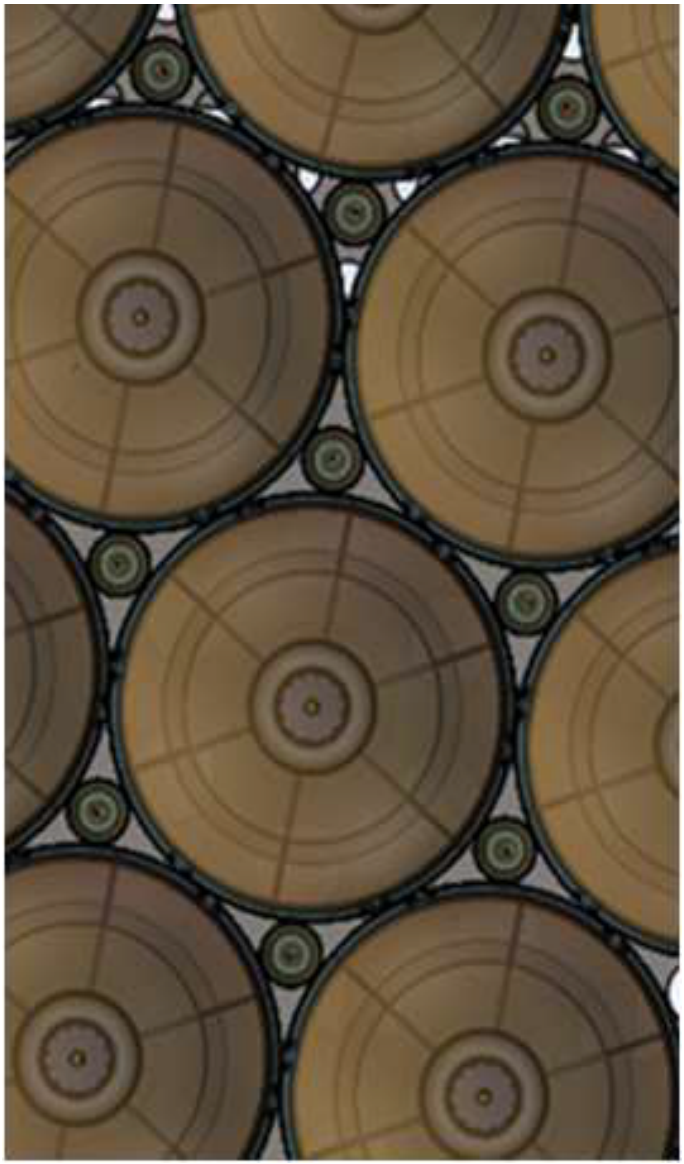
- **20'' PMT photon range [10^{-1} - 10]**

Nonlinearity contributes to non-uniformity
→ deterioration of the energy resolution
CHALLENGE: calibrate the non linear response to sub-percent level
SOLUTION:

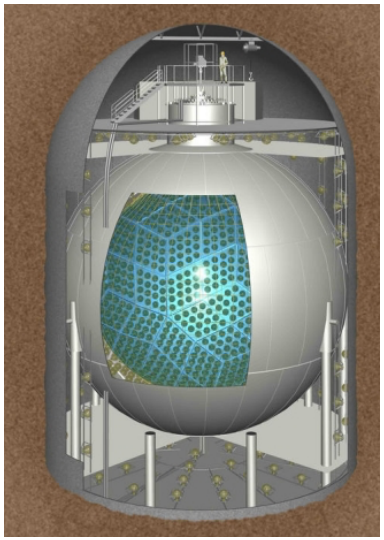
- ✓ **Look at the same events with another dynamic range**
- ✓ **Interleave in JUNO another detector always in the SPE dynamic range**

Stereo-calorimetry

Stereo-calorimetry



JUNO photomultipliers



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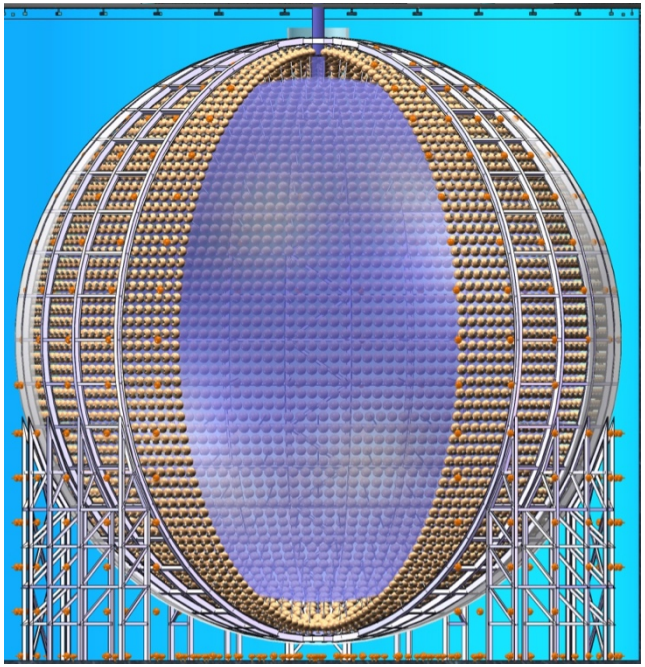
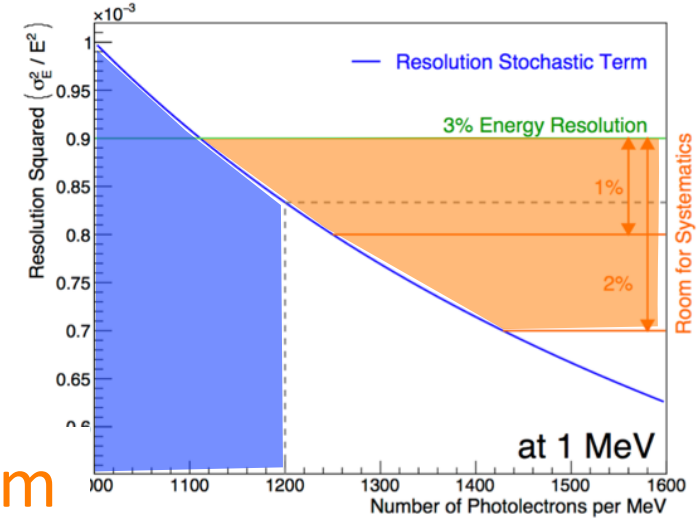
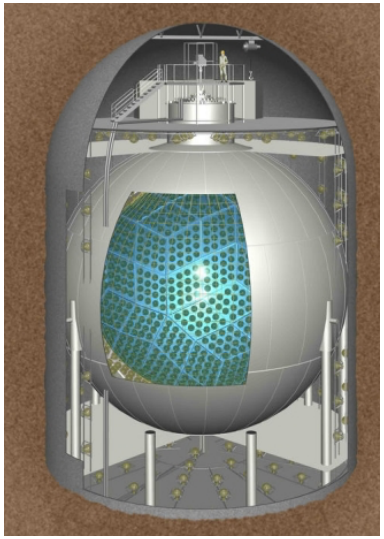


JUNO
20,000 t
➢ **18,000 x 20’’**
75% coverage
1200 PE/MeV
3% /√E
➢ **25,000 x 3’’**
35 PE/MeV
+3% coverage



The *misnamed* **Small PMT (SPMT)** system

JUNO photomultipliers



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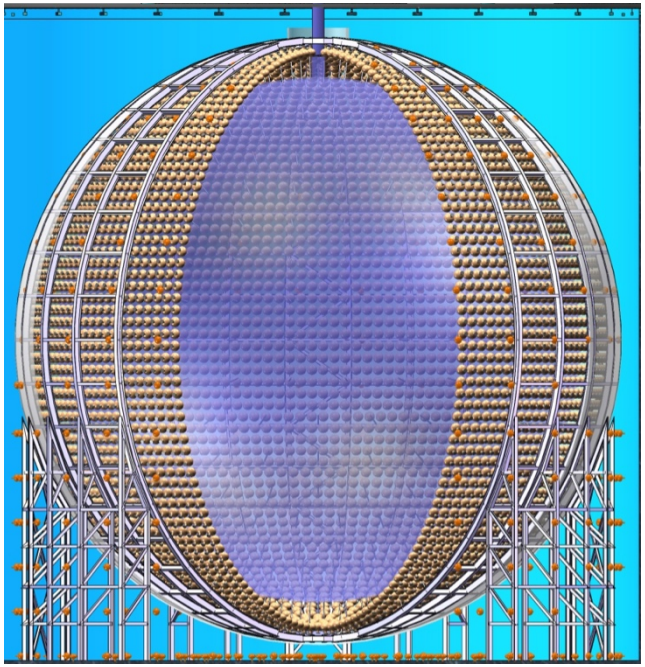


JUNO
20,000 t
- **18,000 x 20''**

75% coverage
3% /√E
- **25,000 x 3''**

20'' NNVT	20'' Hamamatsu
13,000	5,000
TTS 5.1ns	**TTS 1.2ns**
	3''
	25,000
	TTS < 2.5ns

+11% of good timing photocathode

Small PMT (SPMT) system

- **Complete the physics program with good timing & SPE counting**

SPMT physics program

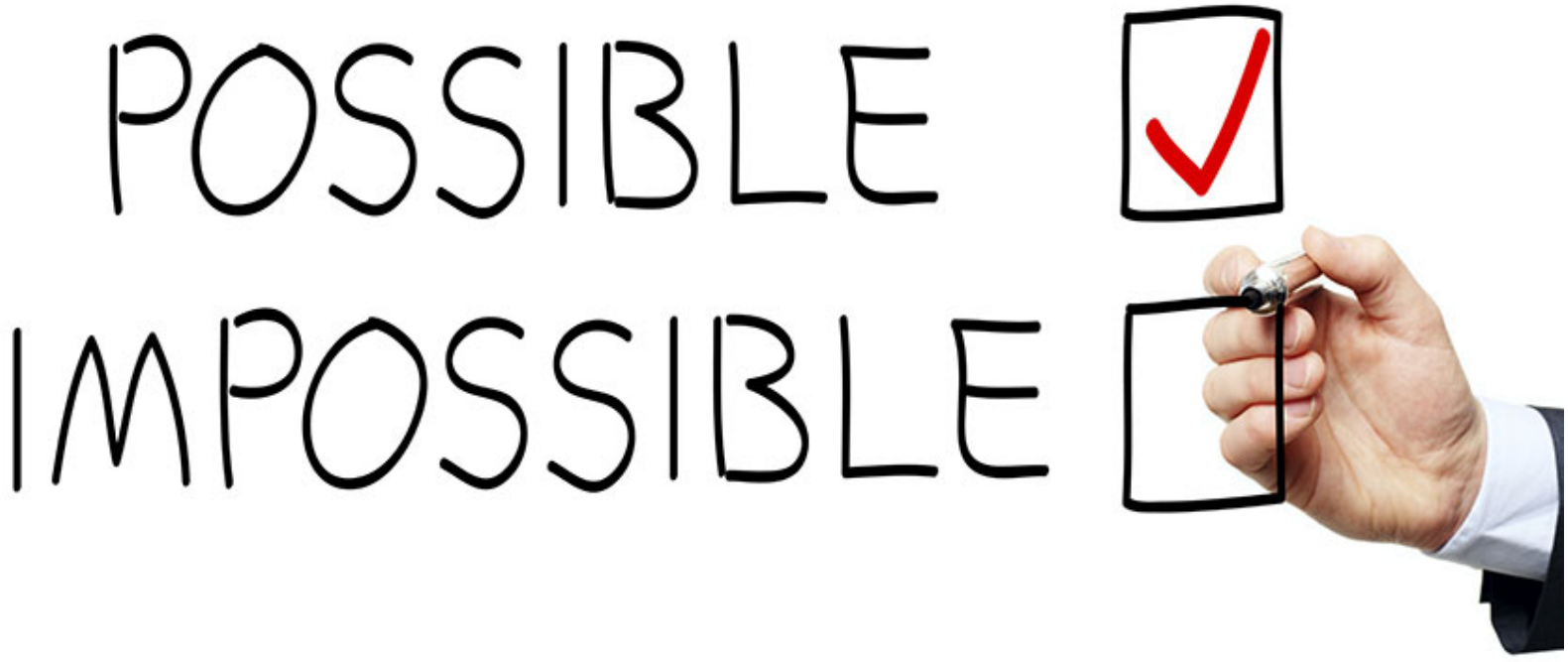
1. High precision calorimetry
   Improve response systematics within IBD physics Aide to achieve ≤3% resolution at 1MeV

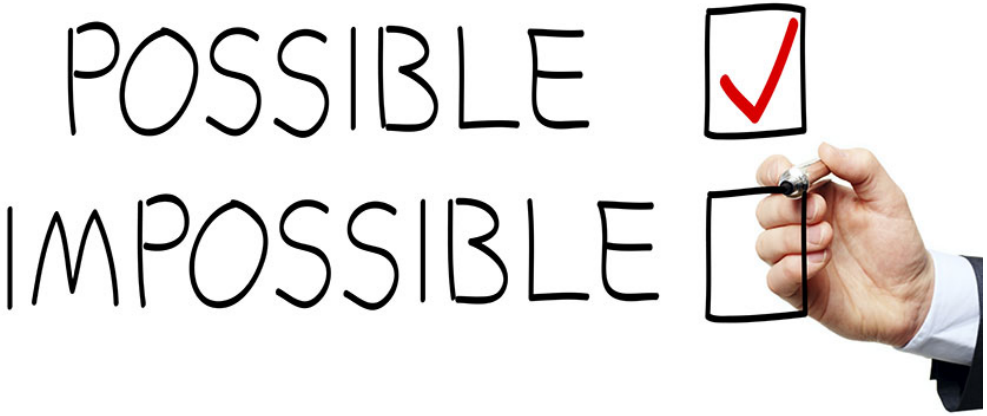
2. Physics: Standalone measurement of solar parameters
   Ensure accurate physics results and validate energy scale

3. Improve inner-detector μ-reconstruction resolution
   Aide $^{12}B/^{9}Li/^{8}He$ tagging/vetoing

4. High rate SN pile-up (if very near)
   Minimise bias in absolute rate & energy spectrum

5. Complementary readout info: time resolution, dynamic range & trigger


POSSIBLE
IMPOSSIBLE



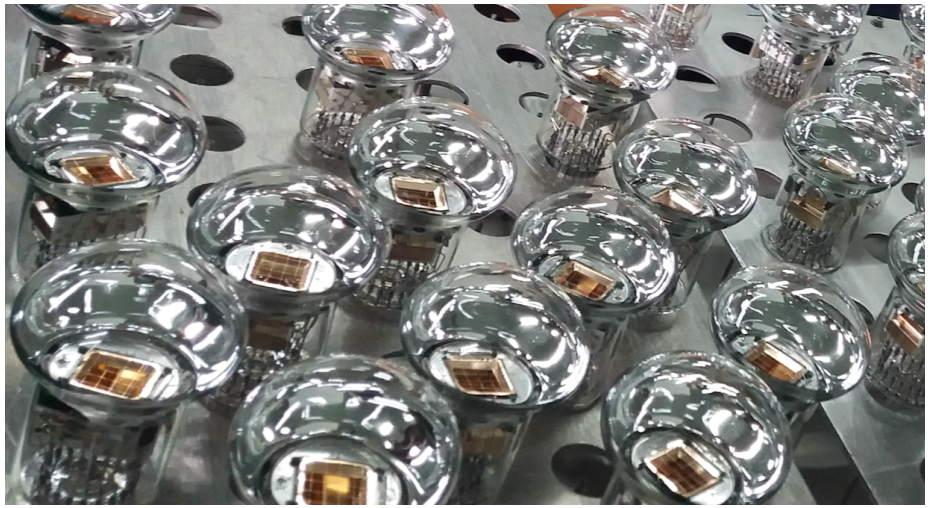
feasibility

25,000 channels → meet industry

The smart path….

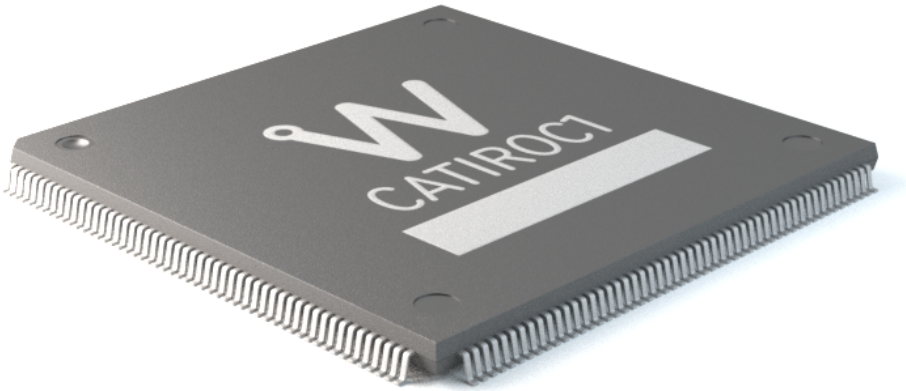
3’’ PMT

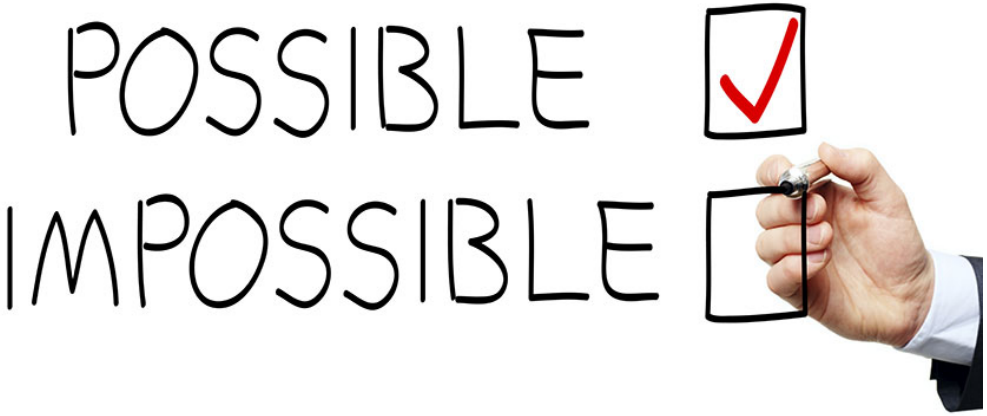
- **Existing** in industry
- **Affordable**
- Good single photon counting system



Readout ASIC

- **Existing** in lab *or industry*
- **Affordable**
- Charge & time / Multi-channel
- SPE readout system

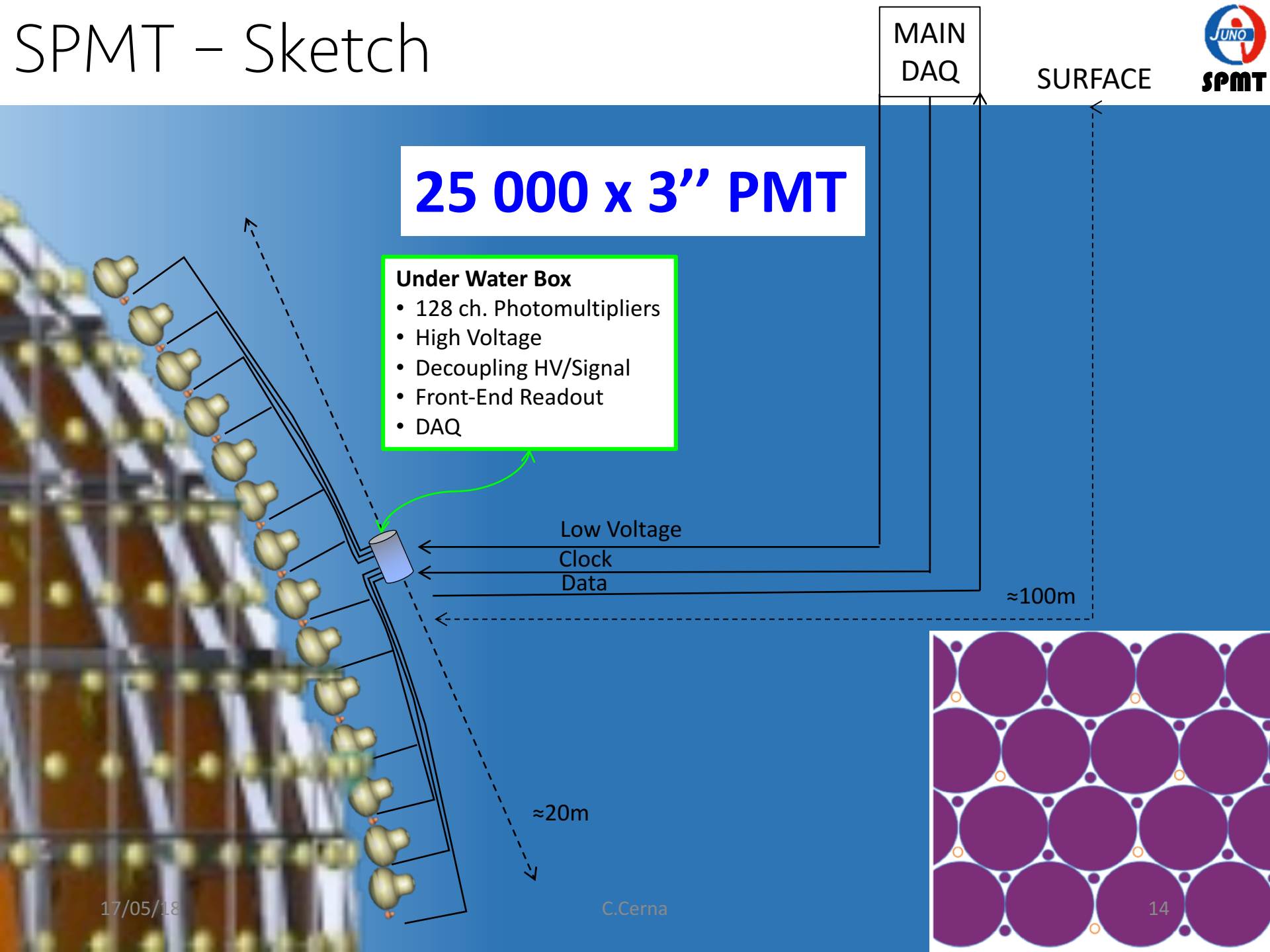




design

easy to produce
easy to integrate
easy to install

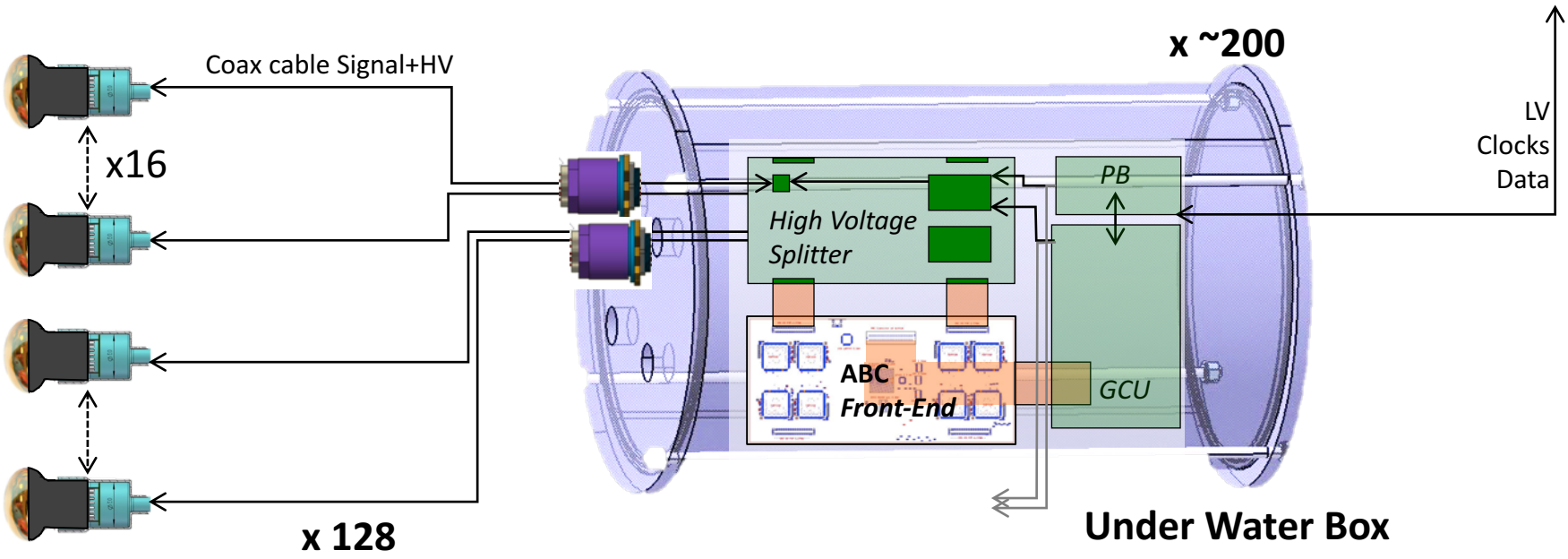
SPMT – Sketch


MAIN DAQ
SURFACE
25 000 x 3” PMT
Under Water Box
• 128 ch. Photomultipliers
• High Voltage
• Decoupling HV/Signal
• Front-End Readout
• DAQ
Low Voltage
Clock
Data
≈100m
≈20m

System schematics

our construction brick

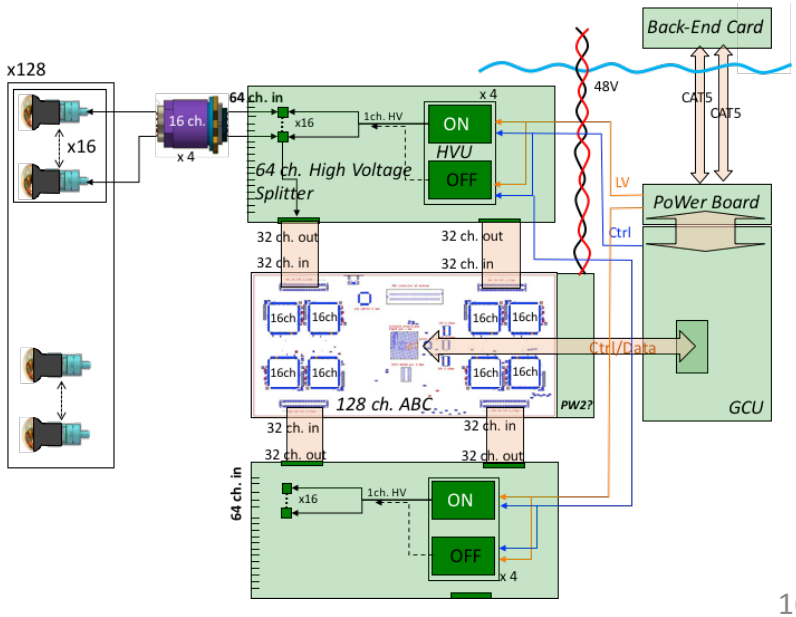
- 3" PMT
- High Voltage divider
- Potting
- Cable
- Connector
- Under Water Box
- ABC board
- Splitter board



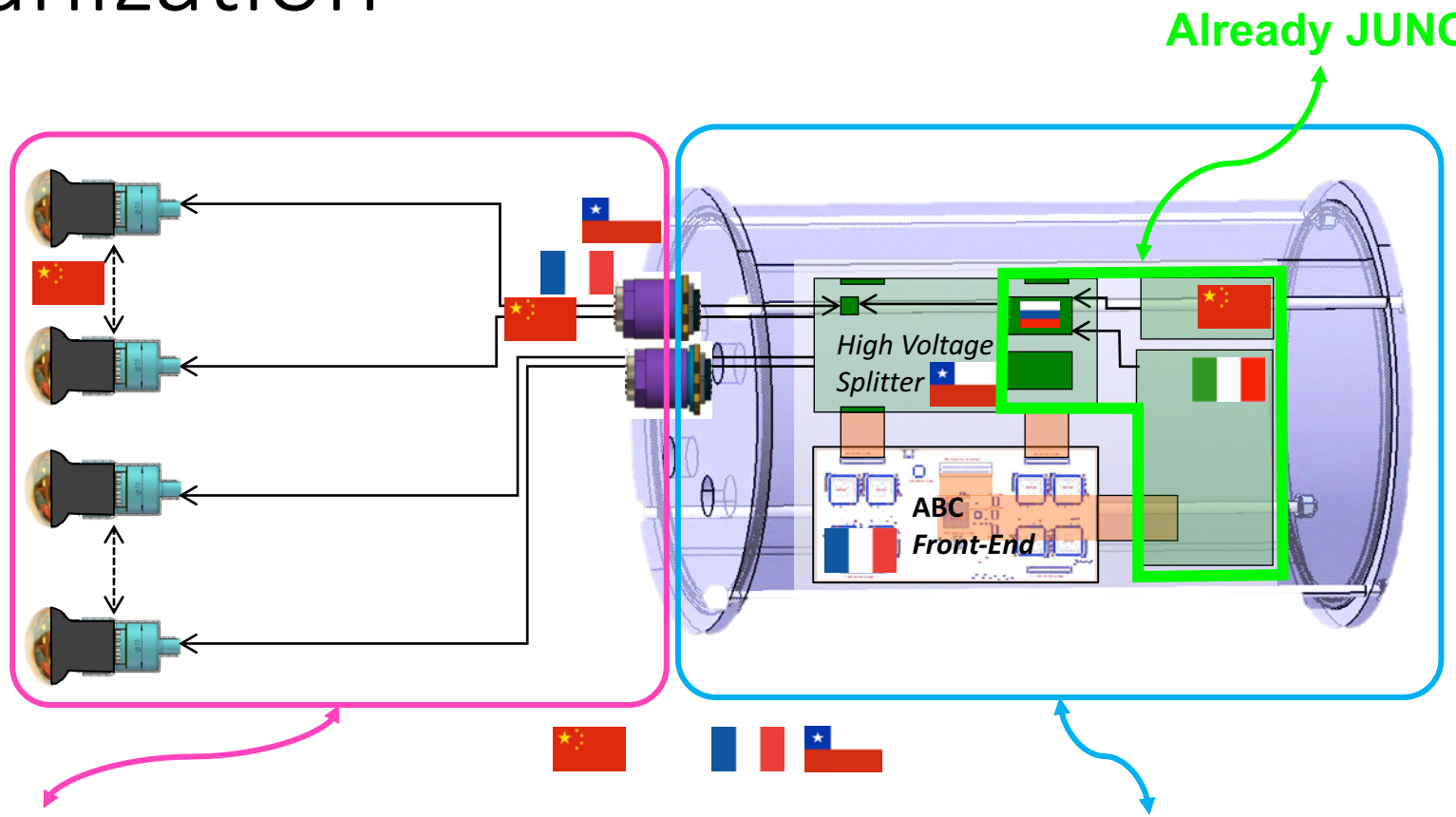
SPMT : the largest funded photomultipliers system…

… and fastest development schedule

earliest idea is 2014 (A.Cabrera) → earliest design is 2015 → Approval by the collaboration as a sub-system 2016 → SPMT consortium → Studies [2016-19] Beginning of production 2018

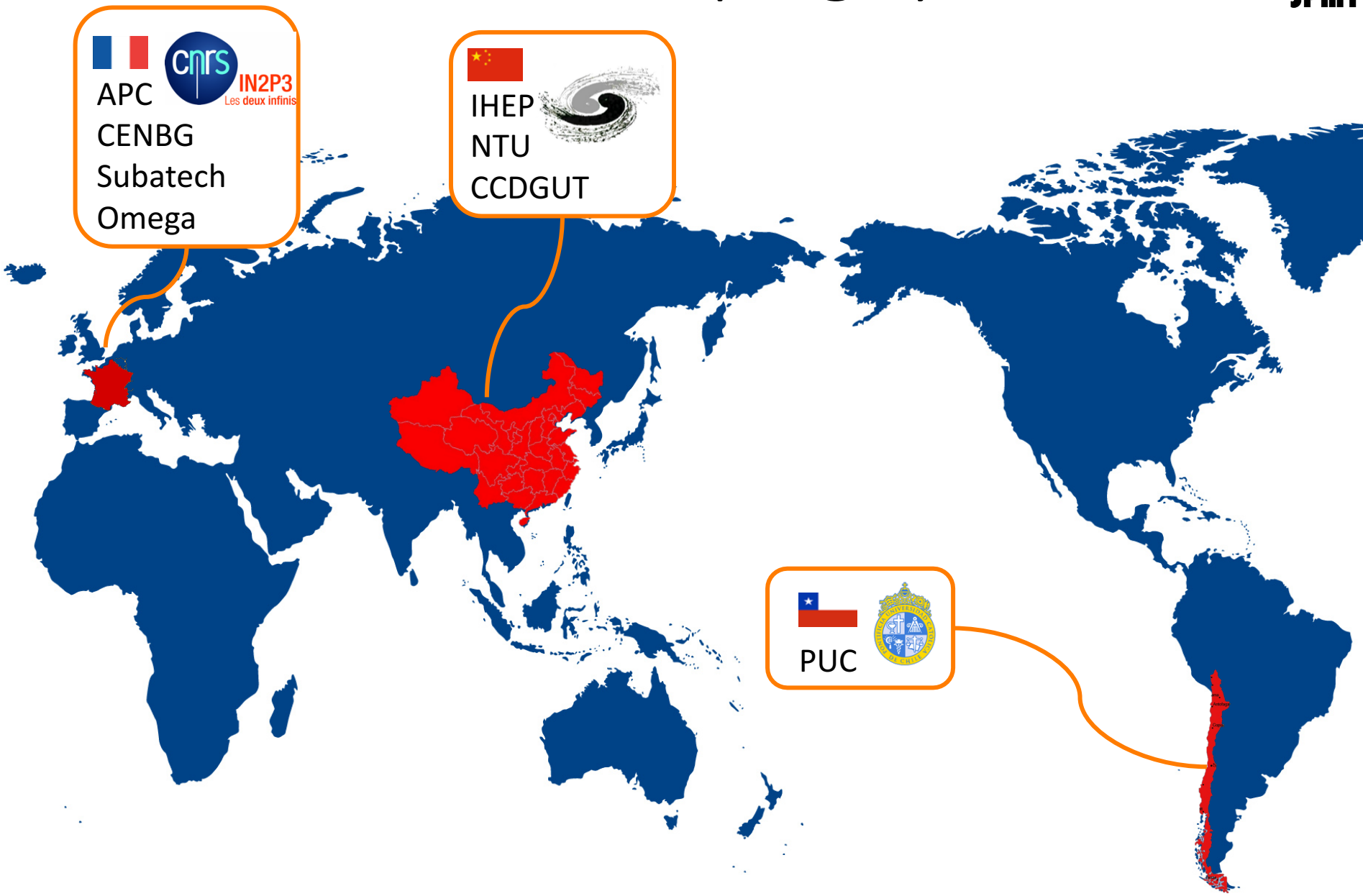


Organization



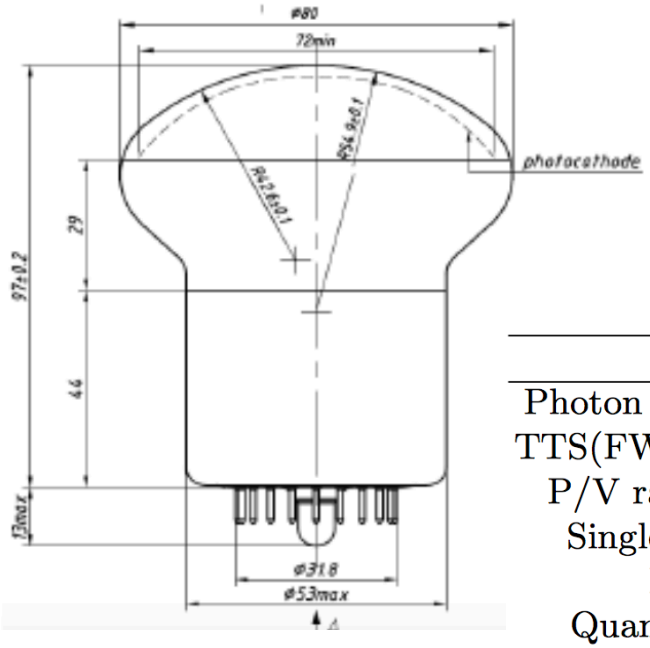
PMT instrumentation and UWB + Electronics are produced at different time, tested separately, and then installed together in JUNO → **underwater connector**

SPMT a never sleeping system



3’’ photomultipliers

July 16 → May 17	• Close work with Hamamatsu, ETEL, HZC, NNVT • Requirements, products, production, prototypes, testing
May 17	Biding at IHEP → HZC to produce 25,000 + 1,000 photomultipliers XP72B22
November 17	Production Readiness Review at HZC
January 18	Production kickoff



Parameters	HZC’s response
Photon detection efficiency@420 nm	24%
TTS(FWHM) of single photoelectron	<5ns
P/V ratio of single photoelectron	3
Single photoelectron resolution	35%
Dark rate @ 0.25 PE	1,000 Hz
Quantum efficiency uniformity	<30% in Φ60 mm
Pre/after pulse charge ratio	<5%/<15%
Nonlinearity	<10%@1-100 PE
Radioactivity	^{238}U<400 ppb, ^{232}Th<400 ppb, ^{40}K<200 ppb

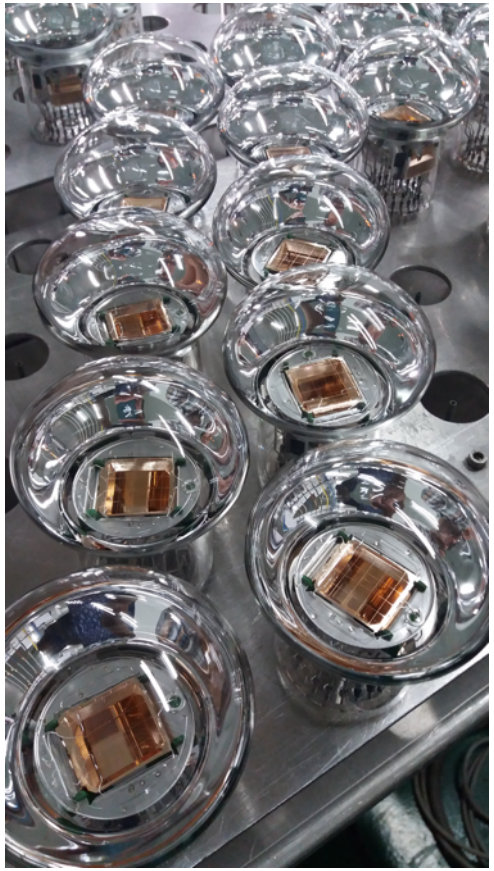
The production started …

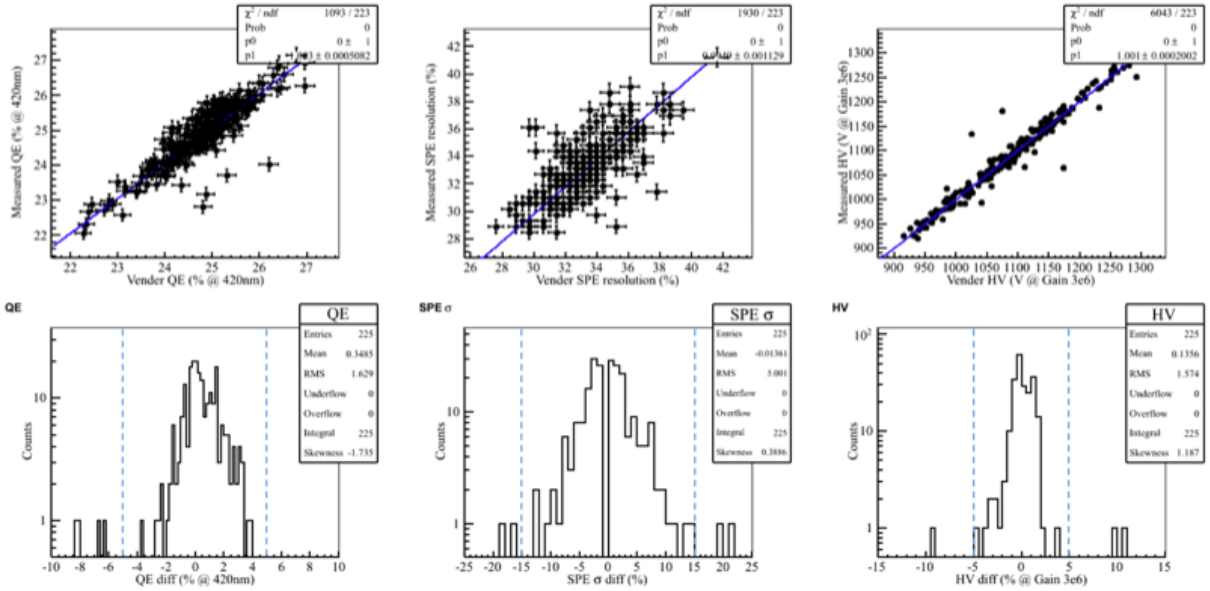
Photomultipliers

- Mass testing of 26,000 photomultipliers is an industrial issue

➢ **HZC produce and test the performances under JUNO supervision**

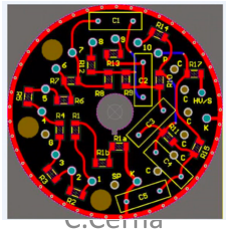
- 100% mass tested by vendor → 10% random tested by IHEP





➢ **Good agreement**

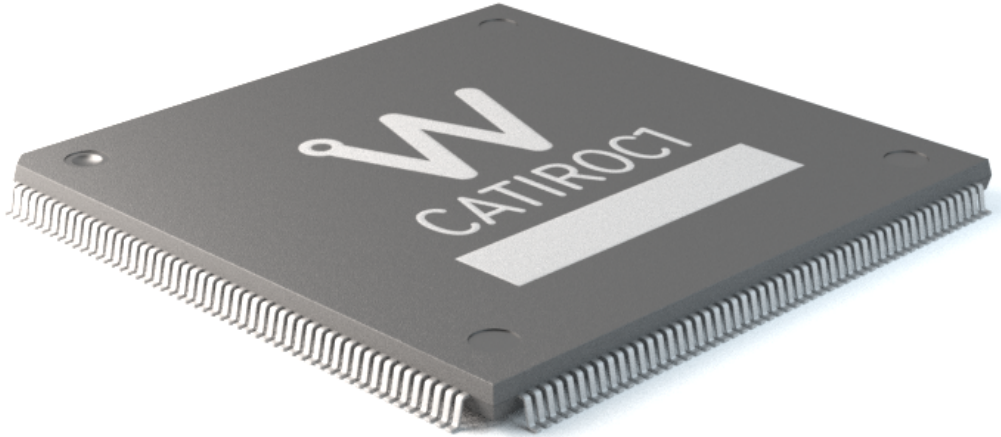
Divider design



Sealing Potting

CATIROC readout ASIC

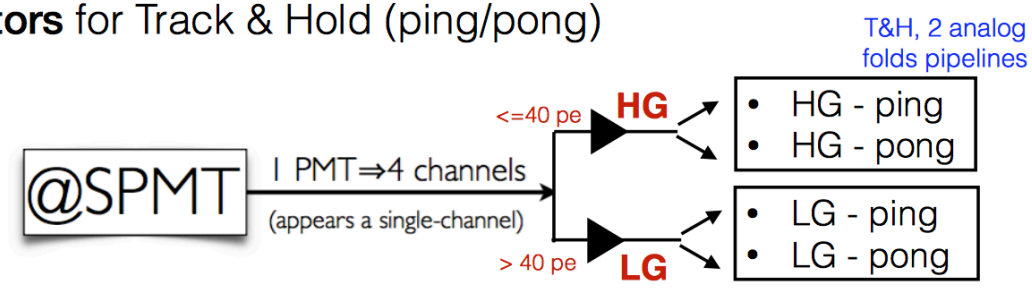
- developed at Omega laboratory (Paris)
- **charge and time** measurements
- **trigger-less system**



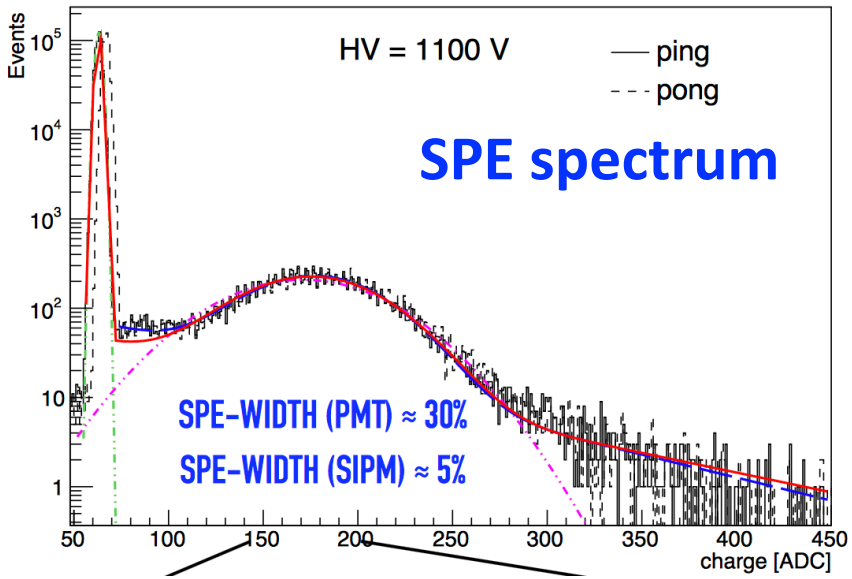
- **16 input** channels
- **pre-amplifier for each channel**
- programmable **trigger threshold** (common to all channels)
- output handled by a FPGA

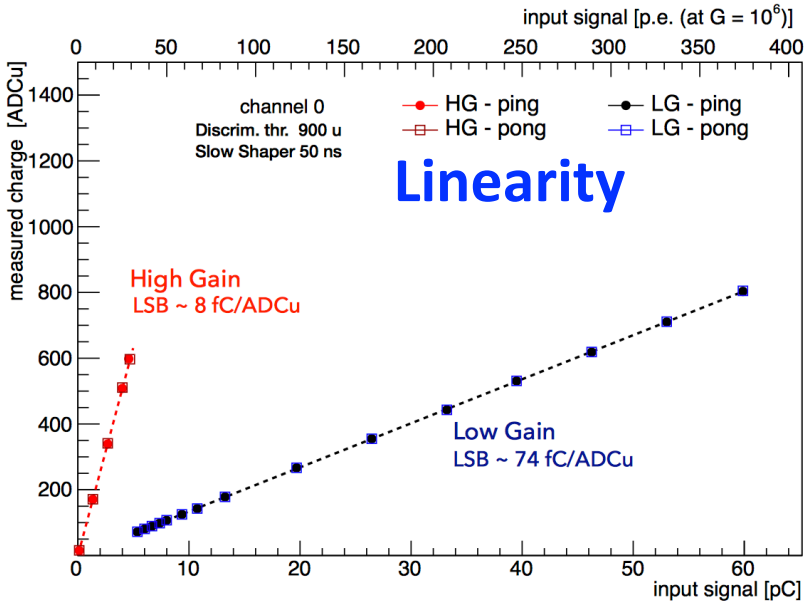
For each channel:

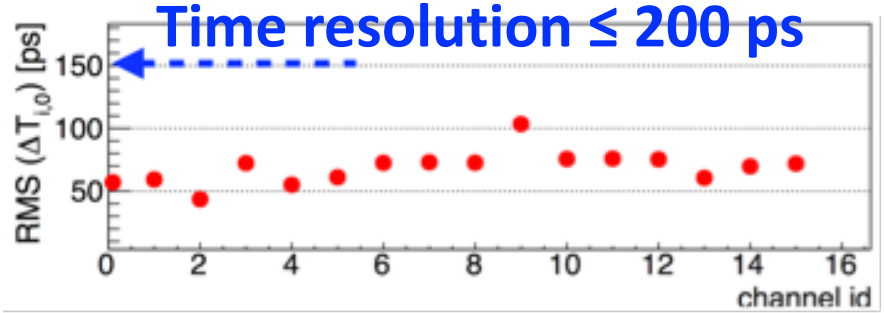
- **x2 pre-amplifiers** (**HG** if q <= 40 p.e., **LG** if q > 40 p.e.)
- **x2 capacitors** for Track & Hold (ping/pong)

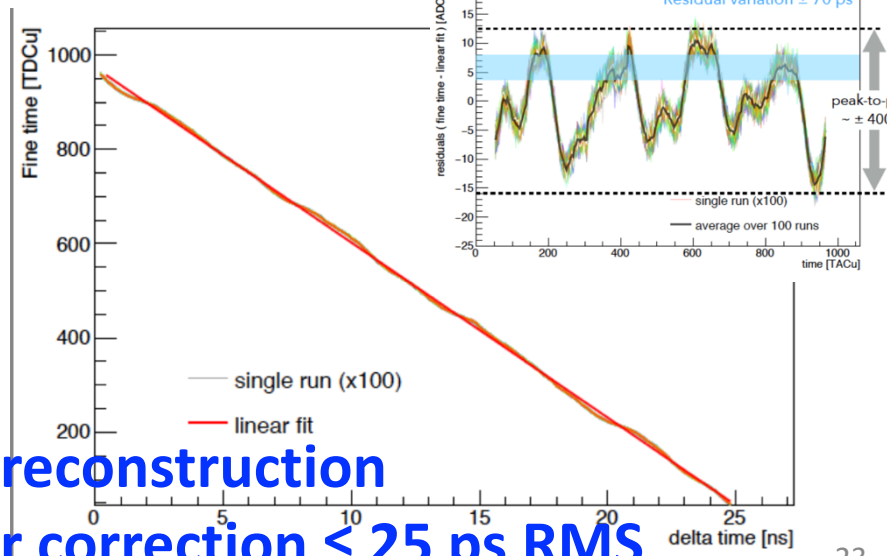


CATIROC Performances



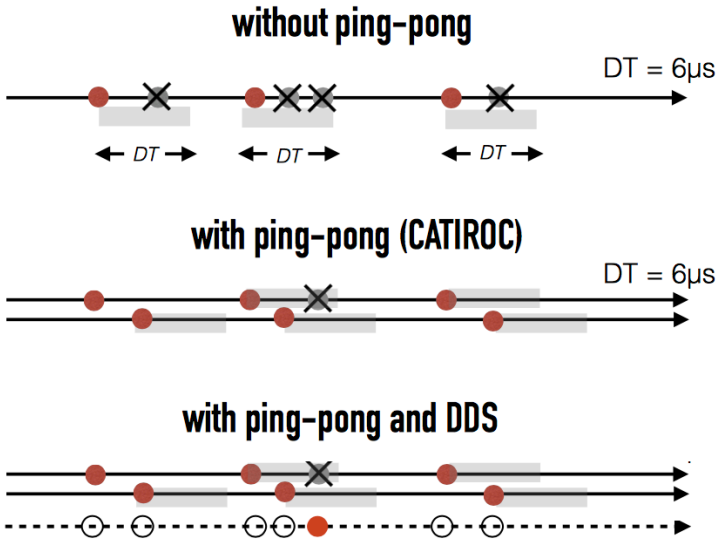




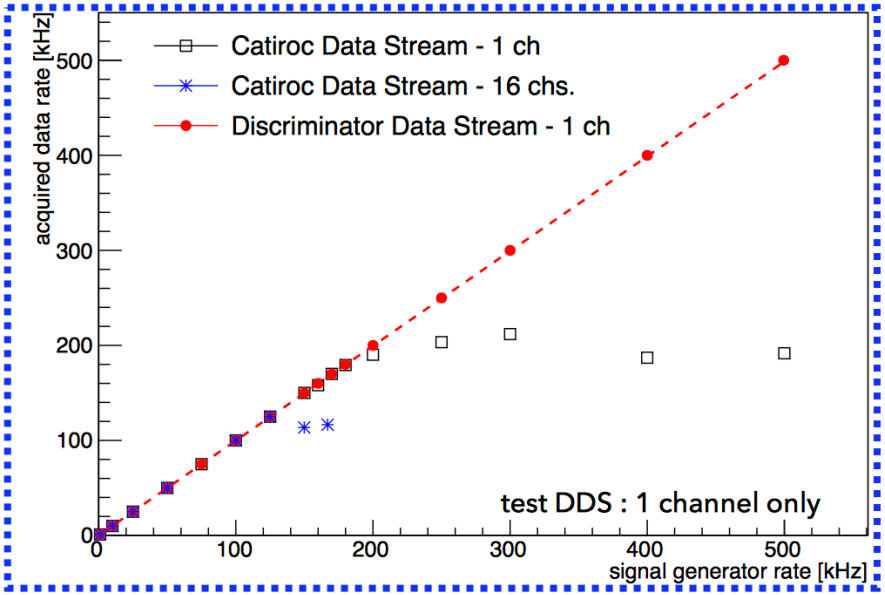


Dead time less system
Dual Data Stream

- Each of the 16 CATIROC channel has **2 readout circuit ping/pong**
- Each ping/pong has **6µs dead time**
- Each channel get a **DISCRIMINATOR output**
  - **in a SPE dominated physics system, use the discriminator as a SPE scaler counter**

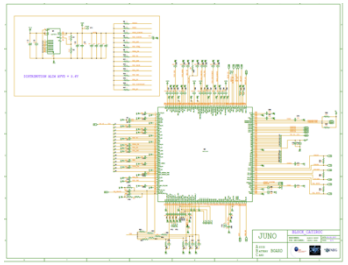


DDS READOUT ≥0.5MHZ!!!



LIMITED BY FPGA

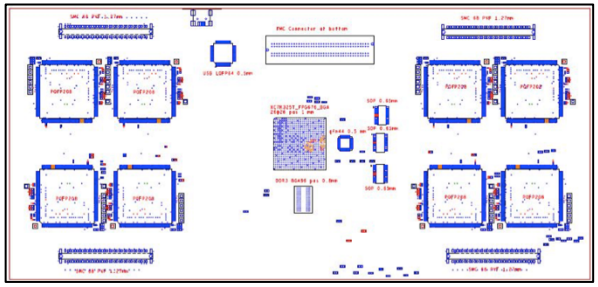
Asic Battery Card front-end board



Design

2016 → April 2017

- **8 CATIROC**
- **1 Kintek 7 FPGA**
- **128 readout channel**
- **Triggerless**



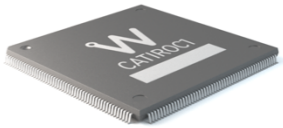
Routing

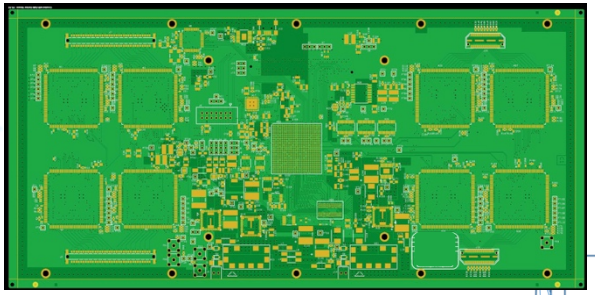
May 2017

CATIROC

32 chips tested

July 2017



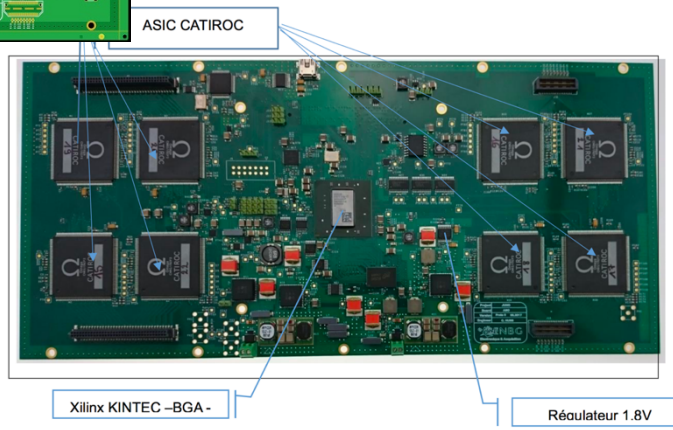


PCB V0

July 2017

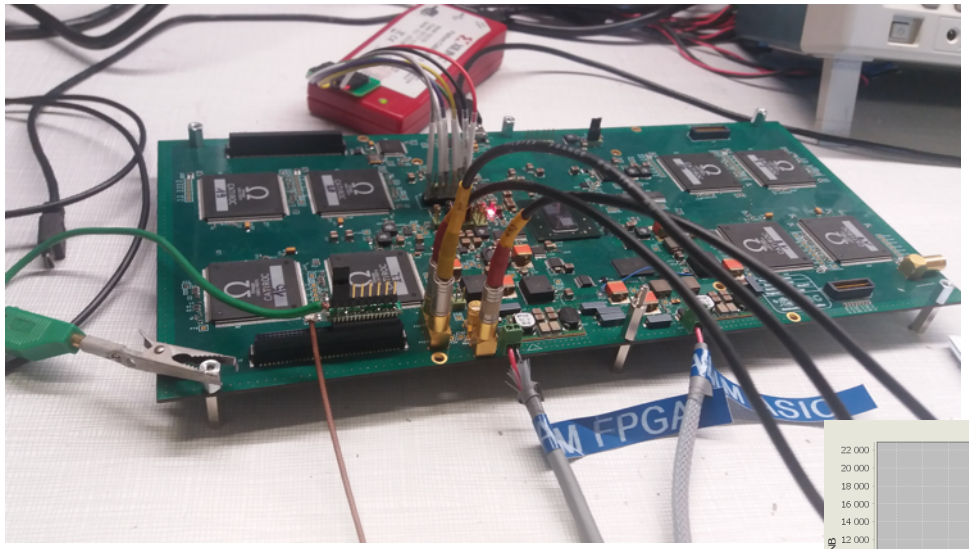
ABC V0

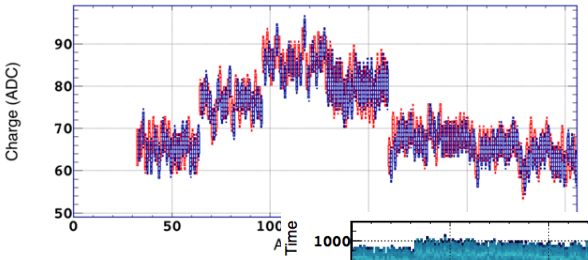
September 2017

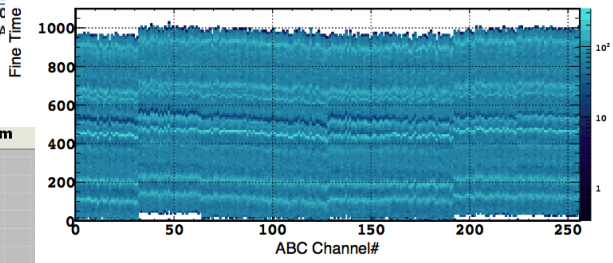


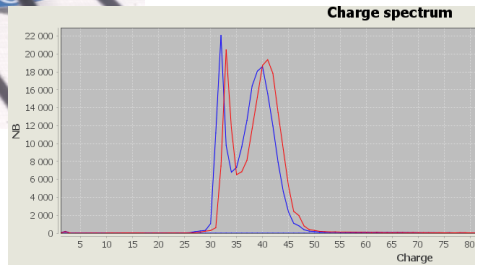
ABC front end board

- ***3 V0 boards in France***
- ***128 channels under study***









From V0 to V1 (final) → Version 1 by fall 2018

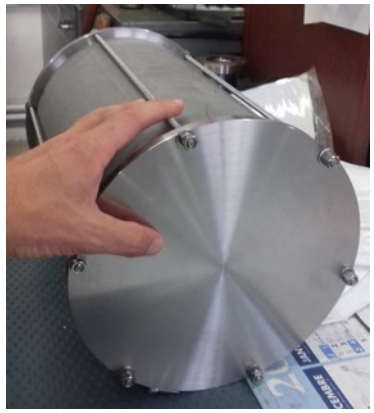
Goal :

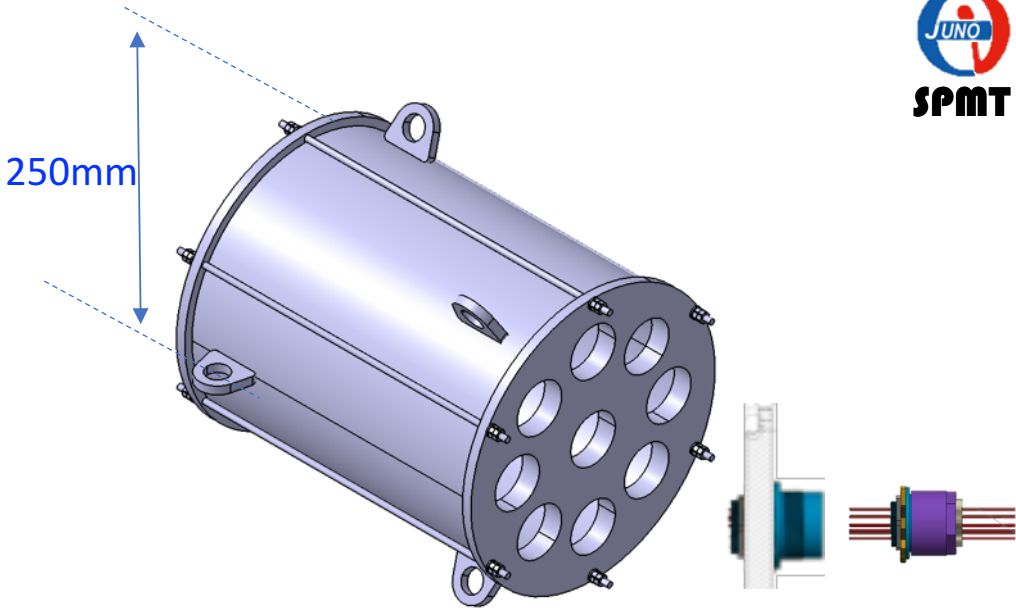
- **CATIROC Production in 2018**
- **ABC Production in 2019**

ABC V0 to be used for the 25,000 Acceptance test setup in China (Subatech)

Under Water Box

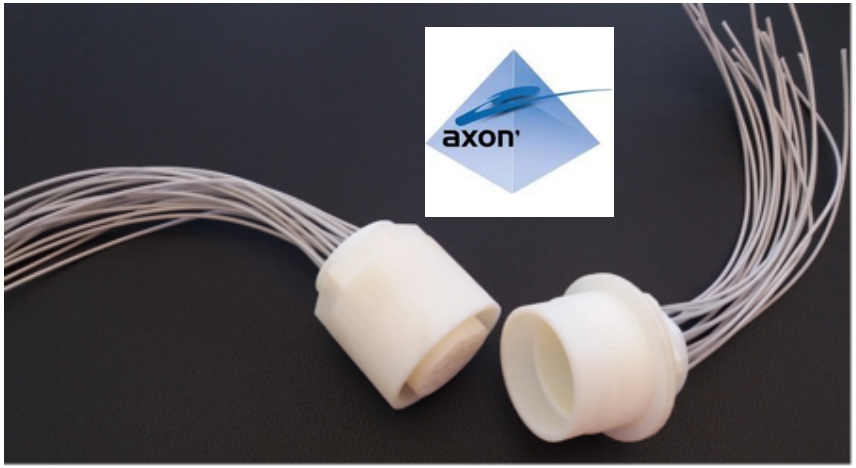
1st Prototypes 2017
FDR end 2018





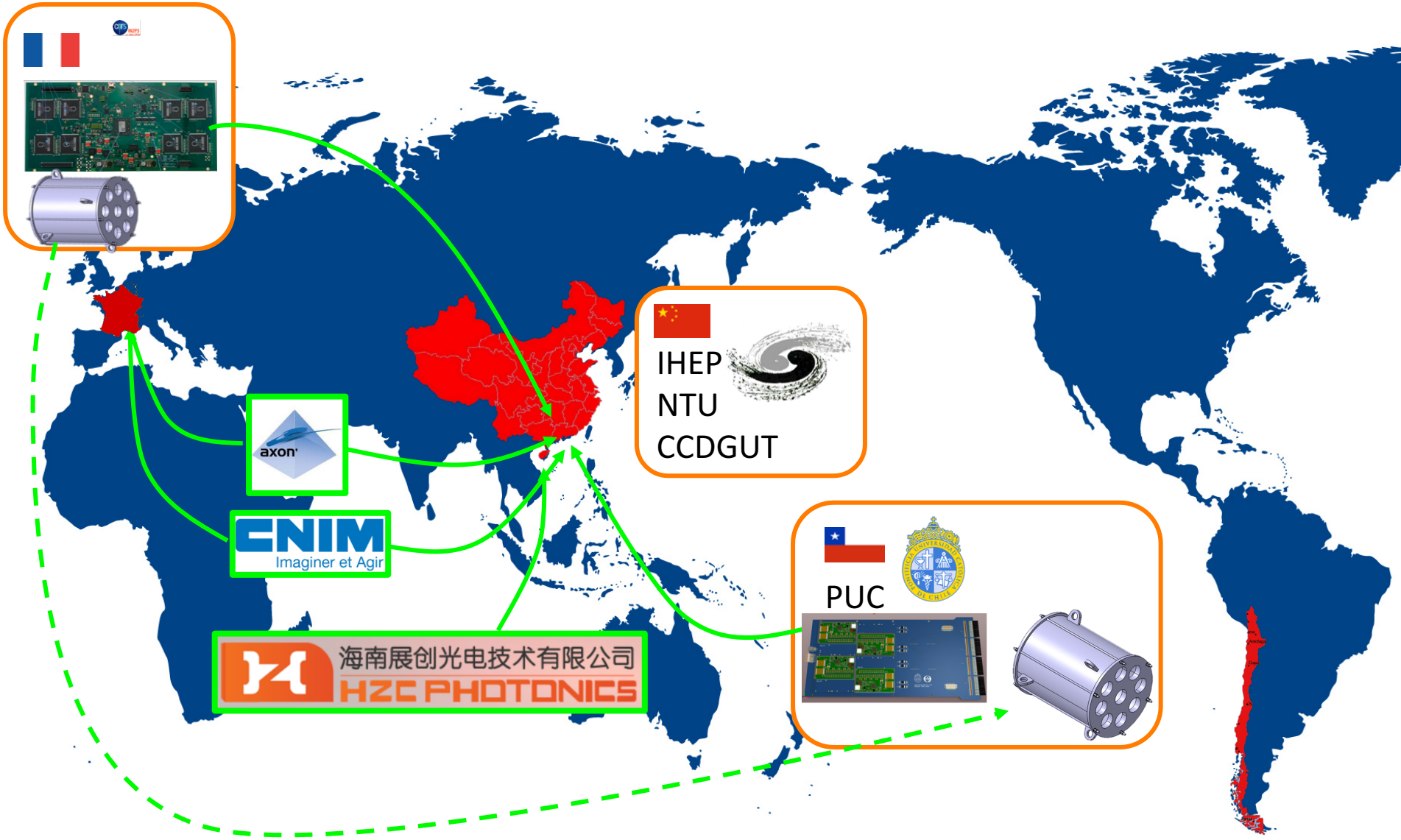
CENBG with CPPM expertise

→ Knowledge transfer to CHILE for production



- **INDUSTRIAL PROBLEM**
- ✓ Custom Cable → DONE
- ✓ Custom 16ch. Underwater connector → Prototypes

SPMT a smart producing system

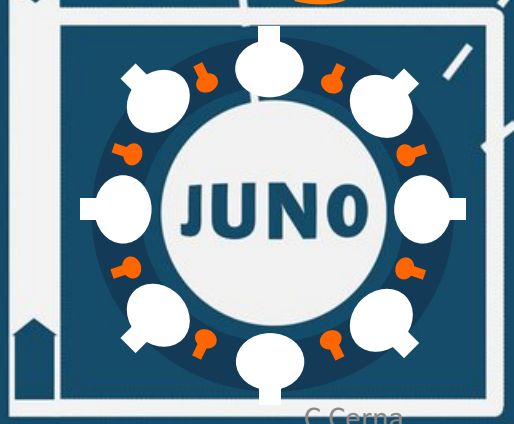


SPMT a smart producing system

JUNO

Small PMT system

everything but small

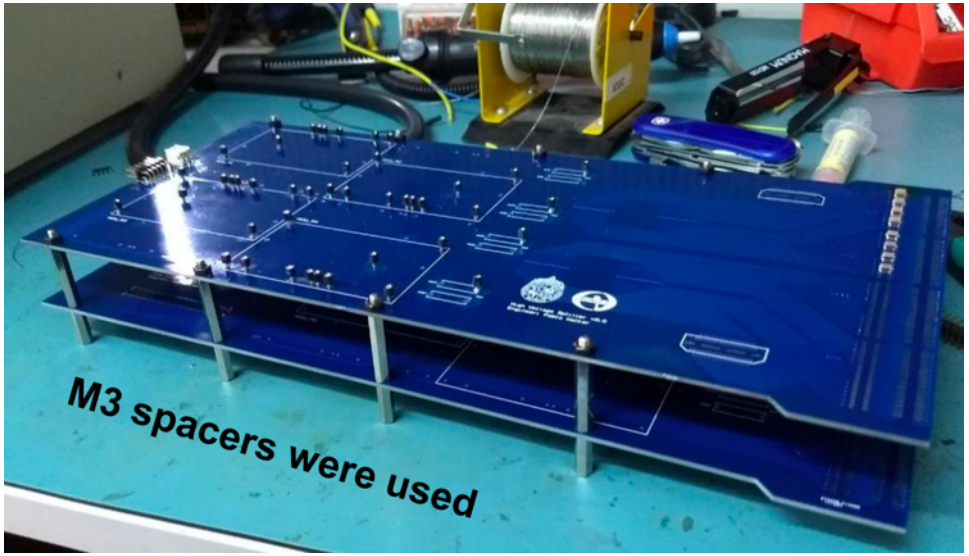


FCPPL – Marseille - May 2018

C.Cerna

on behalf of the JUNO SPMT dream team

HV_Splitter



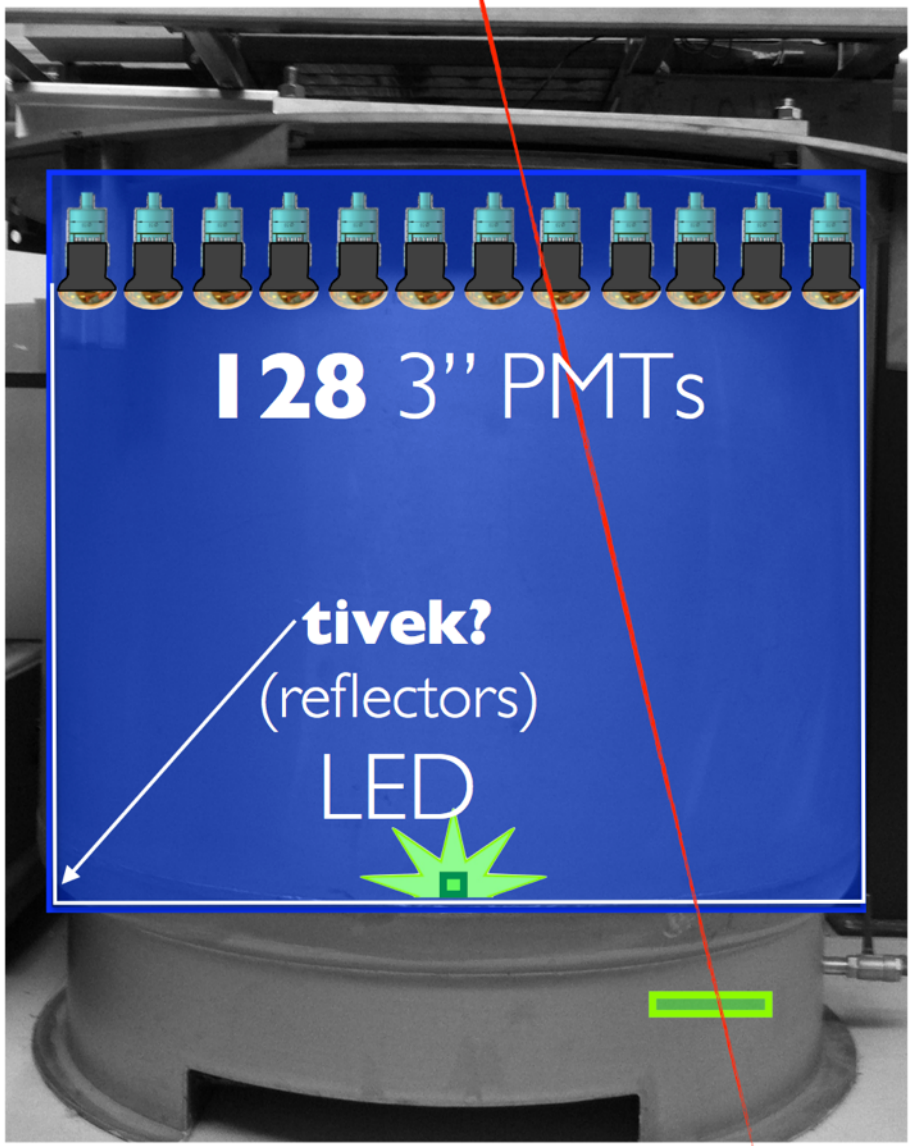
- ***V0 available***
- ***Signals adaptation studies ongoing***

→ *Coupling between **HV_Splitter_V0** and **ABC_V0** by july*
→ *Studies of **HV_Splitter_V0** with **HV_Units** to start ASAP*

From V0 to V1 (final?)

- *Interfaces with ABC*
- *Components*
- *Interfaces with cables*

the JINO detector @IN2P3…

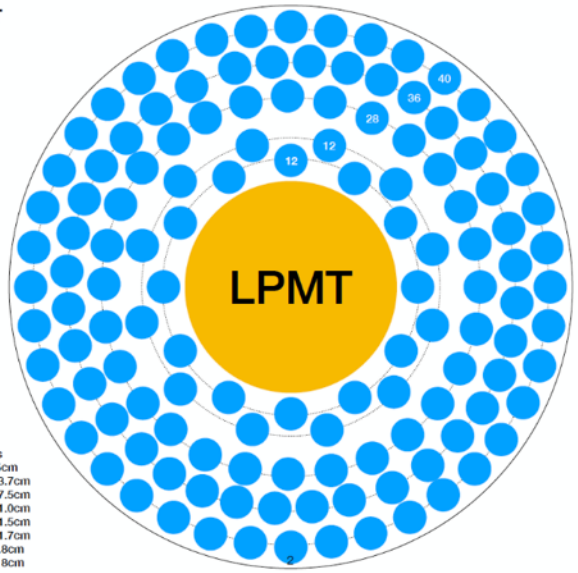


Φ=135cm M≤1.4tons

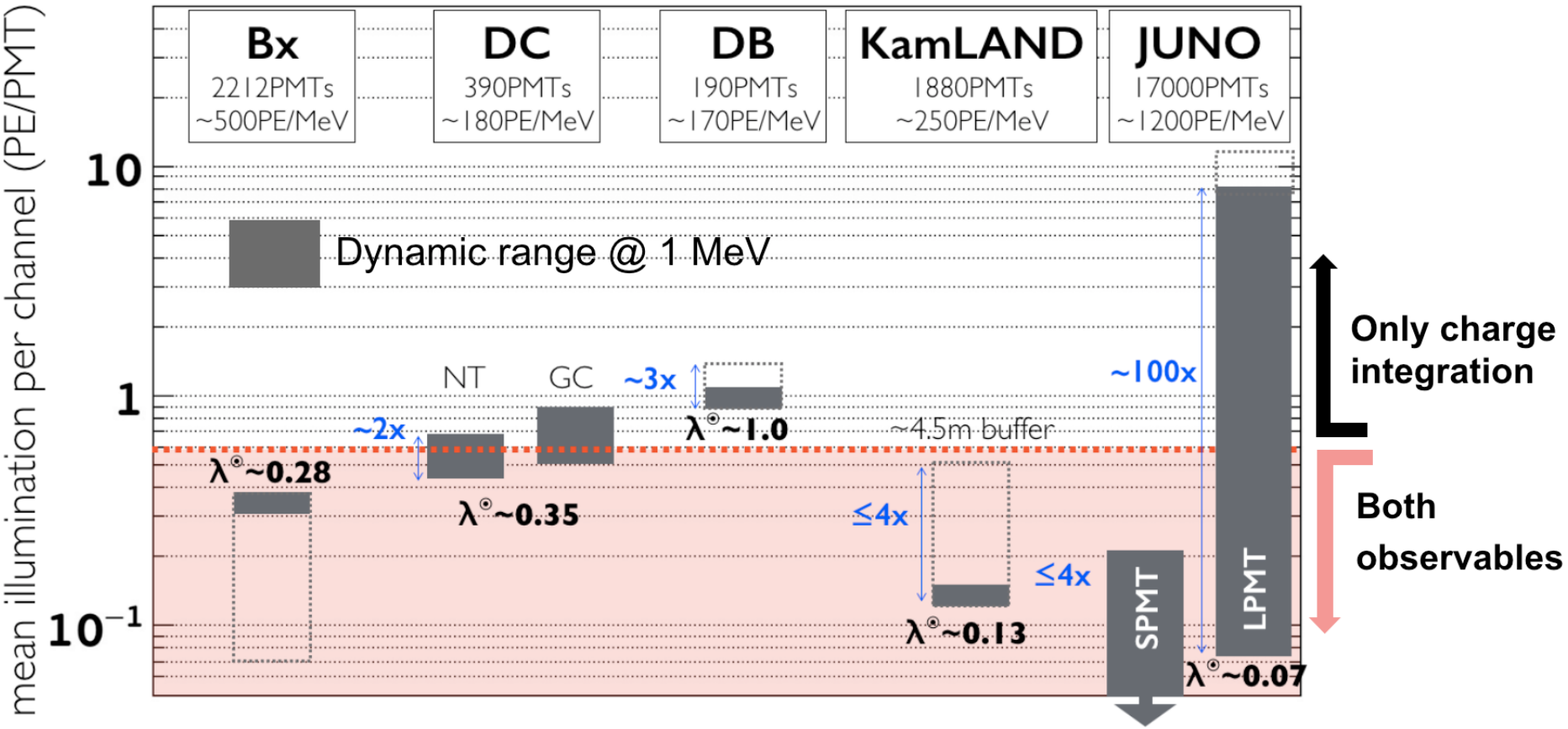
JINO main goals…

- full system integration
- electronics/DAQ validation
  - → ABC card performance
  - → multi-card synchronisation
- supernova high rate optimisation
- IBD energy calibration
- stereo-calorimetry data-driven
- pre-installation full system validation

128 SPMT
+
1 LPMT



Diameters	
Vessel:	135cm
Circle #1:	123.7cm
Circle #2:	107.5cm
Circle #3:	91.0cm
Circle #4:	71.5cm
Circle #5:	61.7cm
LPMT:	50.8cm
SPMT:	8cm


Bx
2212PMTs
~500PE/MeV
DC
390PMTs
~180PE/MeV
DB
190PMTs
~170PE/MeV
KamLAND
1880PMTs
~250PE/MeV
JUNO
17000PMTs
~1200PE/MeV
mean illumination per channel (PE/PMT)
10
1
10^{-1}
Dynamic range @ 1 MeV
NT
GC
~3x
~2x
~100x
~4.5m buffer
$\lambda^{\odot}$~1.0
$\lambda^{\odot}$~0.28
$\lambda^{\odot}$~0.35
≤4x
≤4x
$\lambda^{\odot}$~0.13
SPMT
LPMT
$\lambda^{\odot}$~0.07
Only charge integration
Both observables